



US005757886A

United States Patent [19]

[11] Patent Number: 5,757,886

Song

[45] Date of Patent: May 26, 1998

[54] PROCESS FOR CONVERTING THE BEAM DIAMETER OF RADIOACTIVE RAYS AND A RADIATING UNIT

5,528,653 6/1996 Song et al. 378/149

Primary Examiner—Don Wong
Attorney, Agent, or Firm—Kenyon & Kenyon

[76] Inventor: Shipeng Song, 22/F Electronic Science Building, Shen Nan Zhong Road 30, Shenzhen, Guangdong 518042, China

[57] ABSTRACT

[21] Appl. No.: 660,263

[22] Filed: Jun. 7, 1996

[30] Foreign Application Priority Data

Jun. 8, 1995 [CN] China CN95106841.5

[31] Int. Cl.⁶ G21K 1/02

[52] U.S. CL. 378/147; 378/148; 378/150

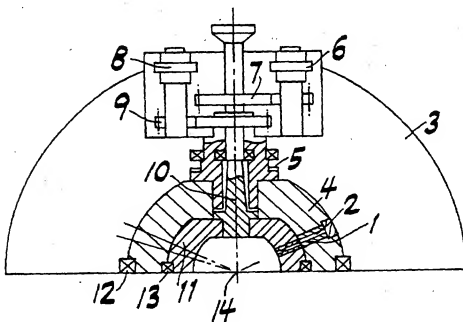
[58] Field of Search 378/65, 64, 147, 378/145, 149, 150, 92, 148

[56] References Cited

U.S. PATENT DOCUMENTS

5,448,611 9/1995 Kerjau 378/65

13 Claims, 1 Drawing Sheet



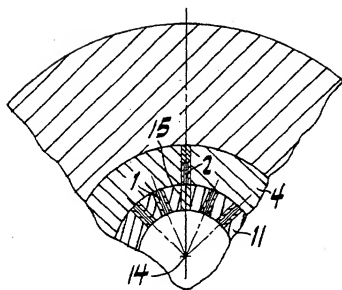


FIG. 1

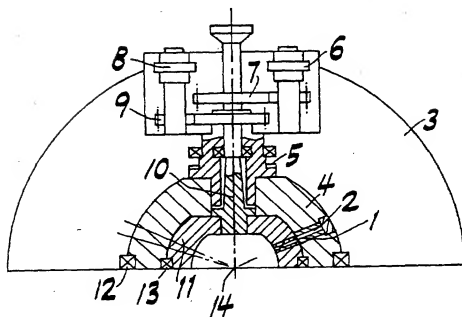


FIG 2

PROCESS FOR CONVERTING THE BEAM DIAMETER OF RADIOACTIVE RAYS AND A RADIATING UNIT

The present invention relates to a process for converting the beam diameter of radioactive rays, especially the process for converting the beam diameter of radioactive rays in a medical stereotactic radiotherapeutic apparatus. The present invention also relates to a medical radioactive source radiating unit. In particular, the radiating unit in a medical stereotactic radiotherapeutic apparatus.

It is necessary to add a collimator on the outlet end of the radioactive source in the medical stereotactic radiotherapeutic apparatus to form the ray beam of specified diameter. To convert the size of the beam diameter of radioactive rays, the conventional process is to mount a set of unique aperture collimators on a special helmet. The aperture of the collimator on the helmet being made in alignment with the passageway of the radioactive source. In use, a set of collimators having an aperture diameter corresponding to the size of the lesion is to be selected. For example, the Leksell Gamma knife produced by the Elekta Corporation, Sweden, is provided with four helmets of different standards. On each of these helmets is mounted a set of final collimator, forming respectively at the site of focus, beams of Gamma rays of 50% dosage and of diameter of 4 mm, 8 mm, 14 mm and 18 mm. Furthermore, there is disclosed in Chinese patent CN-1087551A a rotational conformally-focused Gamma ray radiating unit. In this first generation rotary Gamma knife developed from this patented technology, there are provided five sets of collimator of different aperture diameters and a helmet. The diameter of the Gamma ray beams is to be adjusted by replacement of the collimators. In the case of a complicated shape of the lesion, it is necessary to replace manually the helmet or the collimators for several times when either of the above-mentioned two processes is being used, so as to guarantee the curative effect. In this way, not only the operation is overelaborate but also positioning and safety protection would be a problem.

The object of the present invention is to improve the conventional process for converting the diameter of the radioactive ray beam, so that during the process of medical treatment, the size of the diameter of the ray beam can be conveniently adjusted. To this end, the present invention will also provide a radiating unit to effect this conversion process.

To achieve the above-mentioned object, the solution of the present invention is as follows: In the source base is mounted a set of radioactive sources in such a manner that they are radially in alignment with a common focus on the central axis of the source base. Over a collimator base symmetrical to a central axis are distributed a number of collimators of different aperture diameter. The rule of distribution for each set of collimators is just the same as that for the radioactive sources. The collimator base can rotate relative to the source base about its central axis in order to be positioned, and comes into contact with the inner cavity of the source base. When a set of collimators of a certain aperture diameter is being selected in accordance with the treatment planning system, the collimator base is made to rotate so that the selected collimators come into contact with the radioactive source. When collimators of other aperture diameter are selected, the collimator base can be made to rotate again until another selected collimators come into contact with the radioactive source, so that it is possible for the diameter of the ray beam to be converted during the medical treatment.

To carry out the above-mentioned process for converting the beam diameter of radioactive rays, a radiating unit can be used which comprises a source base, a shielding case, a collimator base, a driving unit and collimator base driving unit. In the source base, a set of radioactive sources are radially in alignment with a common focus on the central axis of the source base. On the collimator base, there are several sets of collimator of different aperture diameter, distributed correspondingly according to the radioactive sources on the source base. In the middle of the collimator base is provided a mandrel. One end of the mandrel is connected with collimator base driving unit via a gear and the other end is fixed in the collimator base.

In the radiating unit mentioned above, the connections of the collimator base with the source base and of the source base with the shielding case are effected by bearings. The source base is provided with a hollow sleeve pipe which can be rotated relative to the shielding case and the mandrel. One end of the hollow sleeve pipe is fixed on the source base and the other end is connected to the source base driving unit via the gear. Normally the source base rotates in low speed to perform the function of rotation focussing. The source base and the collimator base can move relatively to replace the set of collimator and act as shield during non-therapy hours. During the therapeutic process, the source base and the collimator base are relatively stationary. The rotation of the collimator base and the source base is elaborately controlled by the double servo-control system.

According to the present invention, a number of sets of collimators are arranged on the collimator base according to the rule of distribution of the radioactive sources. No helmet is needed, nor is it necessary to replace manually the collimators. In the process of therapy, the beam diameter of the rays can be converted whenever necessary to change the size of the focus. The advantages of the invention are simple construction, convenient operation, enhancement of the accuracy of positioning and the easiness of putting into practice the automatic control by computer. Besides, the addition of a set of shielding rods in the collimator base would enhance safety protection.

The following is a more detailed description of the present invention in connection with the accompanied drawings and embodiments, in which:

FIG. 1 is a diagrammatical view of a specific embodiment of the process for converting the beam diameter of radioactive rays according to the present invention.

FIG. 2 is a structural diagrammatical view of a specific embodiment of a radiating unit for carrying out the process shown in FIG. 1.

With reference to FIGS. 1 and 2, a set of radioactive sources 2 is mounted in a semi-spherical source base 4 radially in alignment with the center 14 of the sphere. Over a collimator base 11 in contact with the inner cavity of source base 4 are distributed several sets of collimators 1 of different aperture diameter. The rule of distribution for each set of the collimators is the same as that for the radioactive sources. FIG. 1 is a partial stretch out view of a conical surface. The center line of a certain radioactive source 2 of a set of radioactive sources on the source base 4 is located on this conical surface. The center lines of four collimators 1 of different inner diameter and center line of a shielding rod 15 are arranged on the same conical surface of the collimator base 11 at a certain angle. When a set of collimators of a certain aperture diameter is designated according to the treatment planning system, the collimator base 11 is rotated to make the selected set of collimators in contact with the radioactive sources 2. The radioactive rays are

being ejected along the collimators. When a set of collimators of other aperture diameter is selected, collimator base 11 can be made to rotate again about the central axis until the selected another collimators comes into contact with radioactive sources 2. In this way, the conversion of the beam diameter of the rays can be realized. In this embodiment, the number of the radioactive sources 2 is 30 and the number of the collimators on collimator base 11 is $4 \times 30 = 120$. Moreover, during non-therapy hours, when collimator base 11 is rotated to make the shielding rods 15 in contact with the radioactive sources 2, the rays can be blocked. The shielding rods is made of heavy metal material, for example, tungsten steel or diluted uranium, to enhance its shielding effect.

In the radiating unit of this embodiment, source base 4 is mounted in a shielding case 3. The collimators of different aperture diameter and the shielding rod corresponding to a certain radioactive source 2 are arranged in the manner shown in FIG. 1. In the middle of the collimator base 11 is provided a mandrel 10, one end of which is connected with the collimator base driving unit 6 via a gear 7 and the other end is fixed on the collimator base 11. Source base 4 and collimator base 11 are connected by means of a high precision bearing 13 so that the collimator base driving unit 6 can be precisely positioned so as to guarantee that the selected set of collimators 1 on collimator base 11 will accurately come into contact with the radioactive sources 2. In the present embodiment, on the source base 4 is mounted a hollow sleeve pipe 5 which can be rotated relative to the shielding case 3 and the mandrel 10. One end of the hollow sleeve pipe 5 is secured on the source base 4 and the other end is connected to the source base driving unit 8 via a gear 9. The source base 4 and the shielding case 3 are connected by means of a high precision bearing 12. The source base 4 is normally rotated in a low speed state to perform the function of rotatory focussing. The source base 4 and the collimator base 11 can be made to move relatively for replacing the collimators and acting as shield during non-therapy hours. During the process of therapy, the source base 4 and the collimator base 11 are relatively stationary. To guarantee the precision of focussing, the mandrel 10 and the hollow sleeve pipe 5 are each provided with an encoder to measure and determine the relative positions of the source base 4 and the collimator base 11. An AC servo motor, a harmonic reducer and an encoder are for use with the collimator base driving unit 6 and the source base driving unit 7. The rotations of the collimator base and the source base are precisely controlled by means of a double servo control system to effect the real time tracking so that the aim for rotatory focussing can be achieved.

The gear 7 and gear 9 of the present invention could be other similar driving units.

I claim:

1. A medical radioactive source radiating unit for converting the beam diameter of radioactive rays, comprising a source carrier (4); a shielding case (3); a collimator carrier (11); a driving member (7); a collimator carrier driving unit (6); and a set of radioactive sources (2), in the source carrier (4) in radial alignment with a common focus (14) on the central axis of the source carrier, characterized in that the collimator carrier (11) is in the inner cavity of the source carrier (4); and in that on the collimator carrier (11) is a plurality of sets of collimators (1) of different aperture diameter distributed in correspondence with the distribution of radioactive sources (2) on the source carrier (4); and in that a mandrel (10) is mounted in the middle of the collimator carrier (11) and has one end connected with the

collimator carrier driving unit (6) via the driving member (7) and the other end fixed to the collimator carrier (11).

2. The radiating unit according to claim 1, characterized in that said collimator carrier (11) is connected with the source carrier (4) by a bearing (13).

3. The radiating unit according to claim 1 or 2, characterized in that said source carrier (4) is connected with said shielding case (3) by a bearing (12); in that a hollow sleeve (5) is mounted on said source carrier (4) and can be rotated relative to said shielding case (3) and said mandrel (10), one end of said hollow sleeve being secured to said source carrier (4) and the other end connected to the source carrier driving unit (8) via a gear (9).

4. The radiating unit according to claim 2, wherein said driving member (7) is a gear.

5. The radiating unit according to claim 3 wherein said driving member (7) is a gear.

6. The radiating unit according to claim 1, characterized in that said driving member (7) is a gear.

7. A process for converting the beam diameter of radioactive rays, comprising the steps of:

mounting a set of radioactive sources (2) in a source carrier (4), in such a manner that the set of radioactive sources is radially in alignment with a common focus on a central axis of the source carrier (4); and

rotating a collimator carrier (11) about its central axis relative to the source carrier (4), the collimator carrier having a plurality of collimators (1) of different aperture diameter distributed thereon, the aperture diameter being selected according to a treatment planning system, said step of rotating being conducted so that the collimator comes into register with the radioactive source (2) on the source carrier (4), wherein said collimator carrier (11) comes into contact with an inner cavity of source carrier (4); wherein the rule of distribution for the collimators (1) on said collimator carrier (11) is the same as the rule of distribution of said radioactive sources (2) on said source carrier (4).

8. The process according to claim 7, wherein the center line of the radioactive source (2) on the source carrier (4) and the lines of the corresponding collimators (1) of different aperture diameter are located along a common conical surface and arranged at a given angle.

9. The process according to claim 8, wherein a plurality of shielding rods (15) of heavy metal are mounted on said collimator carrier (11), the shielding rods having a rule of distribution the same as that of the radioactive sources (2), and wherein the collimator carrier is rotated to bring the shielding rods (15) in register with the radioactive sources (2) during non-therapy hours.

10. The process according to claim 8, wherein said source carrier (4) and collimator carrier (11) are of hemispherical shape.

11. The process according to claim 7, wherein a plurality of shielding rods (15) of heavy metal are mounted on said collimator carrier (11), the shielding rods having a rule of distribution the same as that of the radioactive sources (2), and wherein the collimator carrier is rotated to bring the shielding rods (15) in register with the radioactive sources (2) during non-therapy hours.

12. The process according to claim 11, wherein said source carrier (4) and collimator carrier (11) are of hemispherical shape.

13. The process according to claim 7, wherein said source carrier (4) and collimator carrier (11) are of hemispherical shape.

* * * * *



US006044126A

United States Patent [19]

Rousseau et al.

[11] Patent Number: **6,044,126**[45] Date of Patent: **Mar. 28, 2000**

- [54] **PROCESS FOR AUTOMATICALLY DETERMINING THE CONFIGURATION OF A STEREOTACTIC RADIOSURGERY HELMET TO WHICH CAN BE FITTED A PLURALITY OF COLLIMATORS FOCUSED ON AN IRRADIATION ISOCENTER**

5,627,870 5/1997 Kopecky 378/65
 5,629,967 5/1997 Leksell et al. 378/65
 5,647,663 7/1997 Holmes .

FOREIGN PATENT DOCUMENTS

0 560 331 A1 9/1993 European Pat. Off. .
 91 01279 8/1992 France .
 WO 97 28845 8/1997 WIPO .

Primary Examiner—David P. Porta
Attorney, Agent, or Firm—Wolf, Greenfield & Sacks, P.C.

ABSTRACT

Process for determining the configuration or configurations [treatment time (TT_i)/diameter ($\phi_{i,p}$) of each collimator] of a helmet for stereotactic radiosurgery, to which can be fitted a plurality of collimators focused on an irradiation isocenter, consisting in automatically optimizing, through iterative dose calculation, the dose (D_p) received at predetermined optimization points (M_p), by modifying, in the course of the successive iterations, the treatment time (TT_i) of at least one shot (i) and the diameter ($\phi_{i,p}$) of at least one collimator (C_i) of at least one shot (i), and by calculating, at each iteration, an objective function (OF) having as variables the differences between the calculated dose (D_p) and the expected dose (ED_p) for each point of optimization (M_p), iterative calculation of the doses being carried out automatically until the objective function (OF) satisfies a predetermined optimization criterion.

- [75] Inventors: Jean Rousseau; David Gibon, both of Lille, France

- [73] Assignees: CH&U de Lille; Centre Oscar Lambret-Centre Regional de Lutte Contre, both of Lille Cedex, France

- [21] Appl. No.: 09/102,216

- [22] Filed: Jun. 22, 1998

- [30] Foreign Application Priority Data

Jun. 23, 1997 [FR] France 97 08064

- [51] Int. Cl.⁷ A61N 5/10

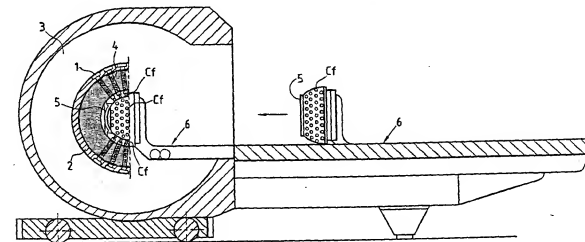
- [52] U.S. Cl. 378/65; 378/148; 600/1

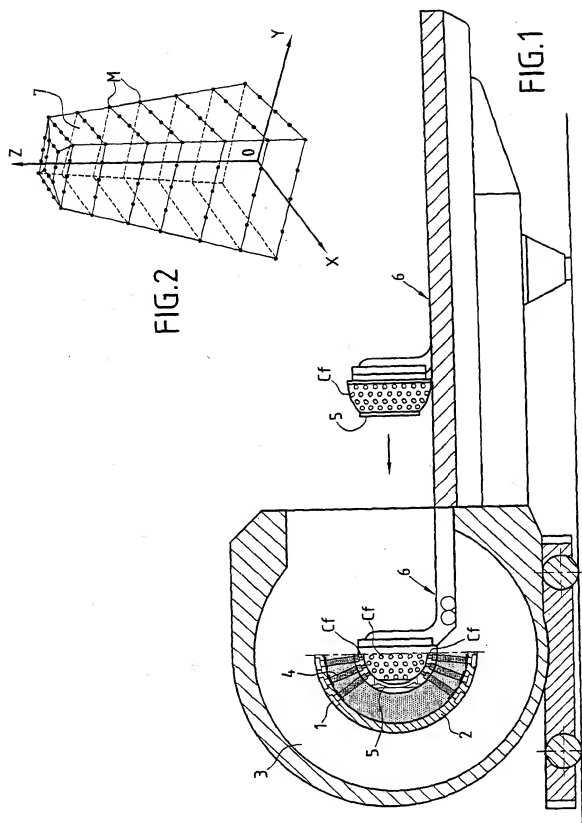
- [58] Field of Search 378/64, 65, 68,
 378/148, 150; 600/1

- [56] **References Cited**

U.S. PATENT DOCUMENTS

4,780,898 10/1988 Sundqvist .
 5,315,360 5/1994 Sturm et al. .
 5,602,892 2/1997 Liacer 378/65

10 Claims, 2 Drawing Sheets



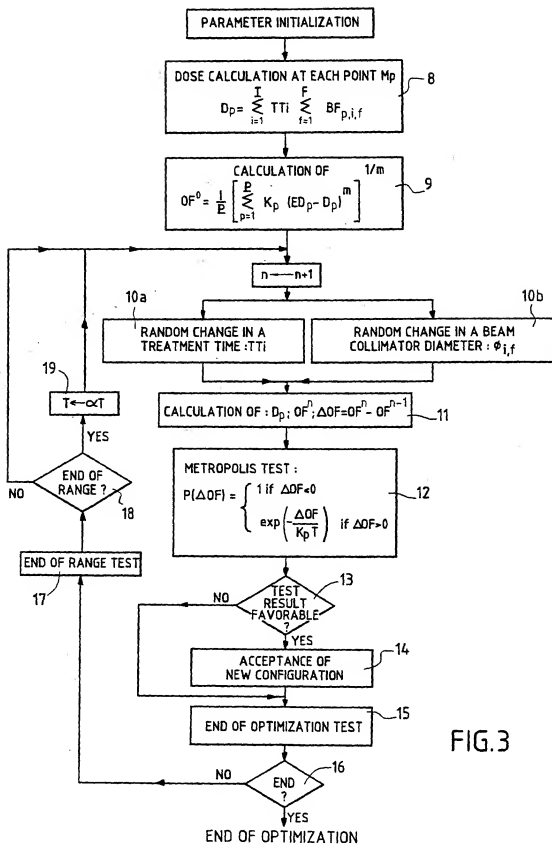


FIG. 3

1

PROCESS FOR AUTOMATICALLY DETERMINING THE CONFIGURATION OF A STEREOACTIC RADIOSURGERY HELMET TO WHICH CAN BE FITTED A PLURALITY OF COLLIMATORS FOCUSED ON AN IRRADIATION ISOCENTER

FIELD OF THE INVENTION

The present invention relates to the field of stereotactic radiosurgery and, more precisely, to radiation therapy for small brain lesions by means of a device making use of a helmet to which can be fitted a plurality of interchangeable, static collimators focused on one and the same irradiation isocenter. It relates more especially, to a process for automatically determining the helmet configuration, or successive helmet configurations, (the diameter of each collimator and the treatment time) according to whether the subsequent treatment plan is of the single-target or multi-target plan.

BACKGROUND OF THE INVENTION

Generally speaking, stereotactic radiosurgery is concerned with radiation therapy for small intracranial volumes and, for example, for arteriovenous malformations, or for tumors. It makes use chiefly, at the present time, of two different techniques that have proved their worth for many years, a dynamic technique and a static technique.

The dynamic technique involves a single source capable of producing a narrow beam of ionizing radiation that is mobile in space in relation to the target volume to be treated.

This first technique makes use of devices mainly constructed on the basis of linear accelerators, and ionizing radiation is mostly produced by a source of high-energy photons.

The static technique makes involve a plurality of ionizing beams which, during treatment, are static in relation to the target volume to be treated, being sharply collimated and focused on one and the same irradiation isocenter. The invention falls within the field of the aforementioned second, static technique, which will now be described in greater detail.

A stereotactic radiosurgery device using the static technique has already been described, for example, in French patent application FR 2 672 220 and in U.S. Pat. No. 4,780,898. Such a device comprises a plurality of sources of ionizing radiation and, for example, radioactive sources of gamma radiation, of the ^{60}Co sources, which are mounted on a hemispherical device facing a plurality of primary collimators, there being one source for each primary collimator. A helmet internal to the aforementioned hemispherical device is fitted with smaller diameter secondary, removable collimators and enables a plurality of isocentric mini-beams to be obtained.

Prior to implementing the treatment, a stereotactic frame is placed on the patient's skull, this frame serving to locate the volume to be treated, known as the 'target volume', in the mechanical coordinate system of the treatment device, using an appropriate medical imaging modality (essentially, X-ray angiography for arteriovenous malformations and Computed Tomography or Magnetic Resonance Imaging in the case of tumoral lesions). The same stereotactic frame is used to position the patient's skull in relation to the helmet of the stereotactic radiosurgery device, in such a way that the irradiation isocenter of the helmet is in a known position in relation to the target volume.

To effect a shot at a given point on the target volume, known as the 'target point', the patient's skull is positioned

2

in such a way that the irradiation center of the helmet coincides with the target point. When all the collimators on the helmet are of the same diameter, the spatial distribution of the dose obtained in a volume assumed to be homogeneous is substantially spherical and centered on the isocenter, the maximum dose being delivered at the isocenter, and the dose delivered at a distance from the isocenter equal to the radius of the collimators substantially amounting to 50% of the maximum dose received by the isocenter. In the static radiosurgery technique, the treatment of a target volume is thus comparable with a punching out operation, during which it is attempted to juxtapose spatially the doses delivered at each shot in such a way as to cover the target volume in its entirety.

In usual practice, as a function of a predetermined target volume for treatment, an operator specialized in radiosurgery decides on a treatment plan, by defining, in a first stage, the number of shots to be effected, and the target point of each shot, that is to say the point on the target volume on which, for a given shot, the irradiation center has to be positioned, and, in a second stage, the configuration of the helmet for each shot. The configuration of the helmet is to be taken here as referring to the diameter of the secondary collimators that have to be mounted on the helmet, and the treatment time for a given shot, that is to say the duration of the shot. The operator can thus decide that a single-target plan, that is to say a single shot on a single target point, is sufficient, if he considers that a single shot will enable a sufficient dose to be delivered throughout the target volume, or, on the contrary, decide on a multi-target plan, effecting a series of successive shots on predetermined target points. The treatment plan and the configuration, or successive configurations, of the helmet must be chosen not only in order to cover the entire target volume with the optimum treatment dose, but also, when the target volume is positioned in the vicinity of a sensitive area, for example in the vicinity of the optic chiasma, taking care to ensure that the dose delivered in this sensitive area, and, generally speaking, outside the target volume, be as small as possible. For this purpose, the operator takes as his basis a certain number of predetermined points for which he knows the optimum dose that ought to be delivered at each of these points these will be, for example, points on the envelope of the target volume, certain points on the inside of the target volume, and, if applicable, certain sensitive points placed outside and in the vicinity of the target volume, and for which the dose must be as small as possible.

Hitherto, and in practice, a specialized operator has had several helmets with which to define his treatment plan, each helmet comprising a number of collimators equal to the number of collimators that can be fitted on the helmet. The collimators for each helmet are of identical or different diameters from one helmet to another. The configuration of the helmet for each shot (diameter of the collimators on the helmet and shot duration) is determined empirically. In order, as a preliminary measure, to validate his choice of configurations and, if applicable, to change it, the operator is provided with a software that enables him, on the basis of each helmet configuration, to effect automatically a three-dimensional calculation of the dose resulting from the set of shots in the case of a multi-target plan, or from a single shot in the case of a single-target plan. The relevance of the configurations for a given treatment plan is gauged by comparing the three-dimensional distribution of the calculated dose with the target volume and, as applicable, with the sensitive volumes.

There are several drawbacks in empirically choosing helmet configurations. The choice necessarily has to be

made by an operator specialized in radiosurgery, on the basis of his experience. It leads, in practice, to a three-dimensional dose geometry which is not best suited to the target volume, which target volume can have any non-spherical contour; as a result, to cover the target volume in its entirety while, at the same time, avoiding, as far as possible, irradiating the area of healthy tissue in the external vicinity of the target volume, the operator has, in practice, to carry out, almost systematically, a series of several shots, knowing that he has a limited choice of collimator diameters. Now, each shot necessitates considerable time for treatment and for positioning the patient, which leads to substantial operating overheads and discomfort to the patient. From a financial viewpoint, and to ensure the patient's comfort, it thus proves necessary to limit the number of shots, and even to be able to reduce the treatment plan to a single shot.

SUMMARY OF THE INVENTION

The invention aims to provide a process for determining the configuration, or successive configurations, of a static stereotactic radiosurgery helmet which overcomes the aforementioned drawbacks. It is based on a process which, on one hand, is designed to be implemented automatically by a suitably programmed calculator, and which, as a result, no longer necessitates any action by a specialized operator, and which, on the other hand, makes it possible to determine helmet configurations for which the collimator dimensions are different for one and the same helmet in such a way that the three-dimensional geometry of the dose delivered is better suited to the target volume. The main advantage as regards treatment is that it is possible to reduce the number of shots.

According to the process of the invention, on the basis: of optimization points (M_n) chosen in relation to the target volume, of an expected irradiation dose (ED_n) at each optimization point (M_n), and of one (a single shot) or several (a series of successive shots) predetermined initial helmet configurations, the dose (D_n) received at each optimization point (M_n) is automatically optimized, through iterative dose calculations by modifying, in the course of the successive iterations, the treatment time (TT) of at least one shot (t), and the diameter ($\phi_{C,t}$) of at least one collimator (C_t) used for at least one shot (t), and by calculating, at each iteration, an objective function (OF) having as variables the differences between the calculated dose (D_n) and the expected dose (ED_n) for each point of optimization (M_n), iterative calculation of the doses being carried out automatically until the objective function (OF) satisfies a predetermined optimization criterion.

Prior to the invention, it had already been proposed to replace certain collimators on a helmet by plugs, for the purpose of locally cutting off one or more isocentric irradiation beams and, by this expedient, of modeling the isodose contour around the irradiation isocenter. However, the method of determining the helmet configurations remained empirical, and was still practiced by a specialized operator, and there has never been any attempt, to date, to combine, on one and the same helmet, collimators having non-zero diameters of aperture that were different.

Generally speaking, within the framework of the invention, the notion of a collimator covers both collimators having a non-zero diameter of aperture and plugs which, for the purposes of generalization are likened to collimators the diameter of which is zero.

BRIEF DESCRIPTION OF THE DRAWINGS

Further characteristics of the process according to the invention will emerge more clearly from a study of the detailed description that follows of a preferred exemplary form of embodiment, which description is given by way of a non-limitative example, and with reference to the annexed drawings, wherein:

FIG. 1 is a diagrammatic representation of a known stereotactic radiosurgery device, corresponding to the static technique;

FIG. 2 illustrates an example of the geometry of an intracranial target volume to be treated; and

FIG. 3 is a flow diagram illustrating the main steps in a particular example of automatic implementation of the process according to the invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

With reference to FIG. 1, a stereotactic radiosurgery device for the treatment of cerebral lesions (arteriovenous malformations or tumors), corresponding to the static technique, includes a plurality of sources, 1, of ionizing radiation, which are arranged, statically, on a hemispherical device, 2, housed inside a shielded cavity, 3, forming a radiation shield, and a helmet, 5, designed to be received inside hemispherical device 2. The latter comprises, for each source 1, a primary collimator, 4, communicating with source 1. Helmet 5 is designed to carry a plurality of isocentric secondary collimators, C_p , which are interchangeable, and which, once helmet 5 is housed inside hemispherical device 2, take up positions respectively facing primary collimators 4. Once helmet 5 is in position inside hemispherical device 2, sources 1 emit ionizing radiation in the form of a plurality of mini-beams which are collimated by primary collimators 4 and secondary collimators C_p , and which are centered on one and the same irradiation isocenter.

Before helmet 5 is placed on the skull of a patient, a stereotactic frame (not shown) is fitted to the patient in the usual way, this frame making it possible, in an initial stage, to locate, in the mechanical reference system of the radiosurgery device, the intracranial target volume to be treated, using a suitable medical imaging modality. This can involve, for example, X-ray angiography, in the case of arteriovenous malformations, and Computed Tomography or Magnetic Resonance Imaging, in that of tumoral lesions. In a second stage, with the patient lying on table 6 of the radiosurgery device, the stereotactic frame is used to position the patient's skull in relation to helmet 5, in such a way that the irradiation isocenter is centered on a predetermined target point on the target volume to be treated. Once this positioning operation has been completed, the radiosurgery helmet 5 fixed to the patient's skull is translated in the direction of hemispherical device 2, until helmet 5 is in position inside hemispherical device 2.

By way of a non-limitative example, the radiosurgery device of FIG. 1 was constituted by 201 sources of ^{60}Co , the initial activity of which was $1.1 \cdot 10^{12}$ Bq. These sources were arranged on hemispherical device 2 facing 201 157 mm long primary collimators 4. Helmet 5 had a diameter of 40 cm, and was capable of carrying 201 60 mm long cylindrical secondary collimators C_p . Each secondary collimator C_p could have a collimating diameter of 4, 8, 14 or 18 mm. Plugs could also be mounted on helmet 5 in place of the secondary collimators, so as to cut off certain irradiation beams. In what follows, these plugs will be considered as

constituting secondary collimators of zero diameter. Helmet 5 thus enabled a maximum of 201 isocentric mini-beams of gamma photons, of 1.17 MeV and 1.33 MeV, emitted by the sources of ^{60}Co , to be obtained. The invention is not, however, limited to a stereotactic radiosurgery device using radioactive sources of gamma radiation of the ^{60}Co source type, and can be applied to any type of stereotactic radiosurgery device which, generally speaking, uses a plurality of isocentric mini-beams of ionizing radiation. This could include, for example, X-rays, proton, neutron or electron radiation.

FIG. 2 shows a particular example of three-dimensional geometry of an intracranial target volume 7 that can be treated using the device of FIG. 1, and located in the mechanical reference system (Ox, Oy, Oz) of the radiosurgery device. In FIG. 2, volume 7 is represented by a plurality of points M delimiting the envelope of target volume 7.

Before helmet 5 is placed on the patient, with a view to subsequently treating a given intracranial target volume, a specialized operator decides, in a first stage, as to the number of shots that will have to be effected, and as to the target point of each shot, that is to say the point on the target volume on which, for a given shot, the irradiation isocenter of helmet 5 has to be positioned. The method of determining the positions of the target points can take the form of empirically trying to ensure optimum coverage of the target volume by a certain number of spheres (one sphere per shot) of different diameters. Each sphere substantially corresponds to the volume that would be irradiated by a shot by means of a helmet 5 on which were mounted only all the secondary collimators of the same diameter. It should also be noted that this method of determining the target points can also be carried out automatically, using suitable software. As this automatic method is known from other sources, it will not be discussed in detail in the present description. It would simply be pointed out that this automatic method resides in optimization of the placing and of the diameters of the spheres by an algorithm of conjugate gradients making it possible to minimize the following objective function

$$OF = \frac{1}{N} \sum_{i=1}^N (d_{iM})^2$$

where:

N is the number of points M (x_M, y_M, z_M) on the envelope of the target volume, and $d_{iM} = (x_M - x_B)^2 + (y_M - y_B)^2 + (z_M - z_B)^2 - r_B^2$, with (x_B, y_B, z_B) and r_B representing, respectively, the co-ordinates of the center and the radius of each sphere.

Once the number of shots and the target points of each shot have been determined, it is necessary, in a second stage, to determine the configuration, or successive configurations, of helmet 5, that is to say, for each shot, the diameters of the secondary collimators C_i that have to be mounted on helmet 5, and the treatment time, that is to say the duration of the shot.

Hitherto, this second stage was necessarily carried out empirically by the specialized operator on the basis of a number of predetermined points for which the operator knew the optimum dose that would have to be delivered at each of these points.

The process according to the invention advantageously enables this second stage to be replaced by a process for automatically determining the configuration, or successive configurations, of the helmet, based on an algorithm for optimization through iterative dose calculation, which can

be implemented by suitably programming any known computer. One particular example of the use of this optimization algorithm will now be described with reference to the flow diagram in FIG. 3.

The main parameters of the flow diagram in FIG. 3 are as follows

M_p (x_p, y_p, z_p): optimization points

P: number of optimization points

K_p : weighting factor assigned to each point (M_p)

ED_p : expected dose at an optimization point (M_p)

D_p : calculated dose at the optimization point (M_p)

I: number of shots

i: shot number (with i ranging from 1 to I)

TT: treatment time for one shot (i)

F: maximum number of beams for a helmet

f: helmet beam number (with f ranging from 1 to F)

$\phi_{c,f}$: diameter of the collimator of the beam (f) of the shot (i)

$BF_{p,i,f}$: dose beam factor that is assigned to each beam (f) of a shot (i), for a given optimization point (M_p), and which is calculated according to the position of the beam (f) in relation to the optimization point (M_p), taking into account the diameter $\phi_{c,f}$ of the collimator corresponding to the beam f and the associated physical data

Kp: Boltzmann's constant

T: control parameter (temperature) of the Metropolis test.

Among the above parameters, the optimization points M_p are points determined by the specialized operator, on the basis of the target volume to be treated. These optimization points are constituted, in practice, by a certain number of points M on the envelope of the target volume to be treated, to which can be added particular points chosen inside the target volume, and points located outside the target volume and corresponding to sensitive volumes for which it is preferable to limit irradiation doses. For each of these optimization points M_p , a defined an expected optimum irradiation dose ED_p . A weighting factor K_p is assigned to each optimization point according to the importance that the specialized operator wishes to ascribe to this point. In other words, the more the specialized operator thinks it important that the irradiation dose that will actually be delivered at this point should be the closest possible to the expected dose, with the helmet configuration, or successive configurations, which have been previously determined automatically, the more this coefficient will be important by comparison with the coefficients assigned to the other optimization points.

Prior to implementing the optimization algorithm according to the flow diagram in FIG. 3, all of the beam factors $BF_{p,i,f}$ that are assigned, for each optimization point M_p to each beam f of a shot i are calculated as a function of the position of the associated beam f in relation to optimization point M_p , that is to say, in particular, as a function of the position of the target point (the irradiation isocenter of the helmet) in relation to the corresponding optimization point M_p , and taking into account the diameter $\phi_{c,f}$ of the collimator corresponding to the beam (f) and the associated physical data, such as, for example, the depth of penetration of the beam at point M_p . This beam factor quantifies the contribution of beam f in the irradiation dose that will be received by optimization point M_p . In the case of a secondary collimator of zero diameter (a plug), the corresponding beam factor will be zero. Such calculation of the beam factors is known per se and will not, therefore, be described in detail herein. For further information on beam factor

calculation, readers are referred to the following publication: Phillips MI: Physical aspects of stereotactic radiosurgery, New York, Plenum Publishing Corporation, 1993.

These beam factors pre-calculated for each beam f and each optimization point M_i will be saved in a table of values which will be accessed automatically during the dose calculation stage, which will make it possible, at the time of implementing the flow diagram of FIG. 3, to avoid having to calculate beam factors, which is costly in terms of computing time.

The different steps of the flow diagram in FIG. 3 will now be discussed. The flow diagram in FIG. 3 is essentially based on an iterative dose calculation DP according to the known formula featuring in block 8 of the flow diagram, and on the evaluation, at each iteration (n), of the value OF^n of an objective function OF according to the formula given in block 9 of the said flow diagram. In this formula, the variable n will be positive which, in a preferred alternative form of embodiment, was fixed at 2.

Initially, one starts out from one or more predetermined initial helmet configurations, depending on whether a single-target or multi-target plan has been decided on. For this purpose, variables TT_i will be initialized to some initial value. Diameters ϕ_{ij} will, for example, be initialized respectively to the values corresponding to the value closest to the diameter of the spheres found when determining the target points. At each iteration (n), one begins by changing one of the helmet configurations, either by changing (step 10a) the treatment time for one of the shots, or by changing (step 10b) the diameter ϕ_{ij} of a collimator. Preferably, at each iteration, steps 10a and step 10b are carried out alternately. More particularly, step 10a will be carried out by effecting a random selection of a number of shot i , and by randomly assigning a new treatment time to the corresponding variable TT_i , for example by adding or removing a predetermined elementary time. Similarly, step 10b will be carried out by randomly choosing one of the numbers of shots j , by randomly selecting a number for beams f , and assigning to variable ϕ_{ij} a given collimator diameter the value of which is randomly taken from among the different possible secondary collimator diameter values that can be used. In the aforementioned example of a radiosurgery device, given by way of illustration, the diameter values were 0 (plug), 4, 8, 14 or 18 mm. Once steps 10a or 10b have been carried out, a calculation is made, in step 11, of the variation in the objective function OF between the iteration (n) and the preceding iteration ($n-1$), and then, two successive tests are applied, namely, respectively, in an initial stage, steps 12 to 14 and, in a second stage, steps 15 to 16.

In steps 12 to 14, a test, commonly known as the 'Metropolis test' is applied to the objective function variation ΔOF , by calculating a probability $P(\Delta OF)$ according to the formula given in step 12 of the flow chart in FIG. 3. See, generally, Webb S. *Optimization by Simulated Annealing of three dimensional conformal treatment planning for radiation fields defined by a multi-leaf collimator*. Phys. Med. Biol. 36 1201-26, 1991.

The step 13 test consists in comparing the probability $P(\Delta OF)$ calculated in step 12 with a figure of between 0 and 1 and taken at random at each iteration (n). If the probability $P(\Delta OF)$ is less than this randomly selected figure, the program branches directly to the second test, known as the 'end of optimization test' (step 15), without choosing the new configuration of the iteration (n) that had been changed by implementation of steps 10a or 10b. On the other hand, if the probability $P(\Delta OF)$ is greater than or equal to the figure taken at random, the new helmet configuration of the

iteration (n) of steps 10a or 10b is accepted (step 14) and the program then goes on to step 15. The Metropolis test illustrated by steps 12 and 13 thus makes it possible, essentially, to determine whether, at a given iteration (n), the new helmet configuration that has been randomly determined in step 10a or 10b is chosen or not chosen.

The second test, in steps 15 and 16, consists in applying an optimization criterion the object of which is to determine automatically whether it is necessary to begin a new iterative dose calculation, or if it is, on the contrary, possible to halt the optimization process. In a precise example of embodiment, step 15 consists in comparing the value OF^n of the objective function with a predetermined threshold. When the OF^n value is below this threshold, the optimization criterion is satisfied, and the iterative calculation process is halted. On the other hand, when the OF^n value is above the predetermined threshold, the optimization criterion is not fulfilled and a new iteration ($n+1$) is begun. More especially, knowing that, in the particular example of FIG. 3, the Metropolis test is applied to the objective function OF, prior to the new iteration ($n+1$), it is automatically checked (steps 17, 18, 19) to see whether it is necessary, as a preliminary, to reduce the control parameter T of the Metropolis test, by multiplying this parameter T , for example, by a coefficient α strictly contained between 0 and 1 and which is fixed, preferably, at 0.9. For this purpose, the number of iterations corresponding to a range of iterations during which parameter T has to be kept constant will have been fixed initially.

In another alternative embodiment, it is also possible to insert an additional test procedure (not shown) between steps 18 and 19 of the flow diagram in FIG. 3 which consists in automatically checking whether, over a given range of iterations, the different successive OF^n values for the objective function that have been calculated have decreased at least once. If not, the optimization procedure is automatically halted. If so, the procedure is continued by going on to step 19, and by beginning a new iteration.

The optimum helmet configurations finally chosen are those for which the value of the objective function OF has been minimum at the time of iterative calculation.

The process according to the invention, whereof a preferred exemplary form of embodiment has just been described with reference to FIG. 3, can advantageously be implemented automatically by means of any suitably programmed computer. At the output, one automatically recovers one (single-target treatment plan) or several (multi-target treatment plan) helmet configurations (treatment time TT_i /collimator diameter ϕ_{ij}), it being possible for the collimator diameters of a given helmet to be different and these diameters having been optimized by calculation so that the real irradiation dose subsequently delivered at each optimization point M_i is as close as possible to the expected dose ED_i at each of these points. As a result, the three-dimensional geometry of the irradiation dose that will be delivered is suited to the shape of the target volume, which advantageously makes it possible to reduce the number of shots, by comparison, for example, with treatment plans for which each helmet used at the time of a shot comprises only collimators of identical diameters.

On the basis of these helmet configurations automatically determined by calculation, the specialized operator can then, in a final stage not forming part of the process according to the invention, perform the treatment on the patient, fitting to the helmet of the radiosurgery device, between each shot, the secondary collimators that are of the appropriate diameter. This placing of the collimators on the helmet between each shot can also be automated, if necessary, by means of a robot

controlled on the basis of the $\phi_{i,p}$ data obtained at the output from the process according to the invention.

We claim:

1. Process for determining the configuration or configurations of a stereotactic radiosurgery helmet (S), to which can be fitted a plurality of collimators (C_p) focused on an irradiation isocenter, each helmet configuration subsequently corresponding to a shot (i) centered on a predetermined target point on a given target volume, characterized in that, on the basis:

of optimization points (M_p) chosen in relation to the target volume,

of an expected irradiation dose (ED_p) at each optimization point (M_p),

and of one (a single shot) or several (a series of successive shots) predetermined initial helmet configuration(s), the dose (D_p) received at each optimization point (M_p) is automatically optimized, through iterative dose calculation, by modifying, in the course of the successive iterations, the treatment time (TT_i) of at least one shot (i), and the diameter ($\phi_{i,p}$) of at least one collimator (C_p) used for at least one shot (i), and by calculating, at each iteration, an objective function (OF) having as variables the differences between the calculated dose (D_p) and the expected dose (ED_p) for each optimization point (M_p), iterative dose calculation being carried out automatically until the objective function (OF) satisfies a predetermined optimization criterion.

2. Process according to claim 1, characterized in that, at each new iteration, the treatment time (TT_i) of a single shot or the diameter ($\phi_{i,p}$) of a single collimator (C_p) used for a single shot (i) are changed alternately.

3. Process according to claim 2, characterized in that the choice, at each iteration, either of the shot (i) and of the associated new treatment time (TT_i), or of the shot (i), of the collimator (C_p) and of the associated collimator diameter ($\phi_{i,p}$) is carried out by random selection.

4. Process according to claim 1, characterized in that the value of the objective function (OF^n) at the iteration (n) is given by the following formula:

$$OF^n = \frac{1}{P} \sum_{p=1}^P [K_p(ED_p - D_p)^m]^{\frac{1}{m}}$$

wherein K_p is a weighting factor, which is assigned to each optimization point M_p , P is the number of optimization points M_p , and m is positive, and is preferably equal to 2.

5. Process according to claim 1, characterized in that, at each iteration (n), the Metropolis test is applied to the objective function variation ($\Delta OF = OF^n - OF^{n-1}$); and:

if the Metropolis test is favorable, the helmet configurations of the iteration n are accepted;

then, the optimization criterion is applied; and:

if the optimization criterion is not satisfied, a new iteration (n+1) is begun starting from the helmet configuration or configurations of the preceding iteration (n-1) if the Metropolis test is unfavorable, or starting from the new helmet configuration or configurations determined at the iteration (n) if the Metropolis test is favorable.

6. Process according to claim 5, characterized in that the control parameter (T) used in the Metropolis test is constant for a predetermined number of iterations, termed the range of iterations, and in that, at the end of each range of iterations, the control parameter (T) used in the Metropolis test is reduced.

7. Process according to claim 6, characterized in that the reduction of the control parameter (T) of the Metropolis test is calculated by multiplying (T) by a factor (α) of between 0 and 1, and, preferably, equal to 0.9.

8. Process according to claim 1, characterized in that the optimization criterion is satisfied when the objective function falls below a predetermined threshold.

9. Process according to claim 1, characterized in that the optimization criterion is satisfied when the objective function has not decreased over a range of iterations.

10. Process according to claim 8, characterized in that the helmet configuration or configurations finally chosen is/are that/those for which the value of objective function OF has been minimal at the time of iterative calculation.

* * * * *